Using biosolids for reclamation and remediation of disturbed soils.

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WHAT ARE BIOSOLIDS?

All municipal wastewater treatment plants produce biosolids which are the stabilized residuals that settle from the water during the various treatment processes. Figure 1 outlines a typical wastewater treatment facility. Solids are produced during primary treatment, as heavy suspended solids settle out. In secondary treatment, microbes eat the dissolved and remaining suspended solids; then, being heavier than water, they also settle out in quiet water. In some cases, tertiary treatment can be used to clean the water even further, and a third type of solids is produced – one that normally involves chemical and physical treatment.

Following wastewater treatment, the collected solids are treated to stabilize the readily putrecible materials, reduce volume and destroy pathogens. Solids treatments are generally biologically based with microbes using the organic carbon in the solids as an energy source. Material produced as a result of solids treatment is called biosolids. Biosolids are generally about 50% organic at the end of typical anaerobic digestion. All biosolids can be used for their fertilizer value. Total nitrogen (N) in biosolids varies with the treatment process, but generally ranges from 1-6% N. Used in agriculture, they are generally applied at rates sufficient to meet the nitrogen requirements of the crop. Because of the high content of organic matter, biosolids are also good soil conditioners. Biosolids can generally be divided into two categories: high N and low N biosolids.

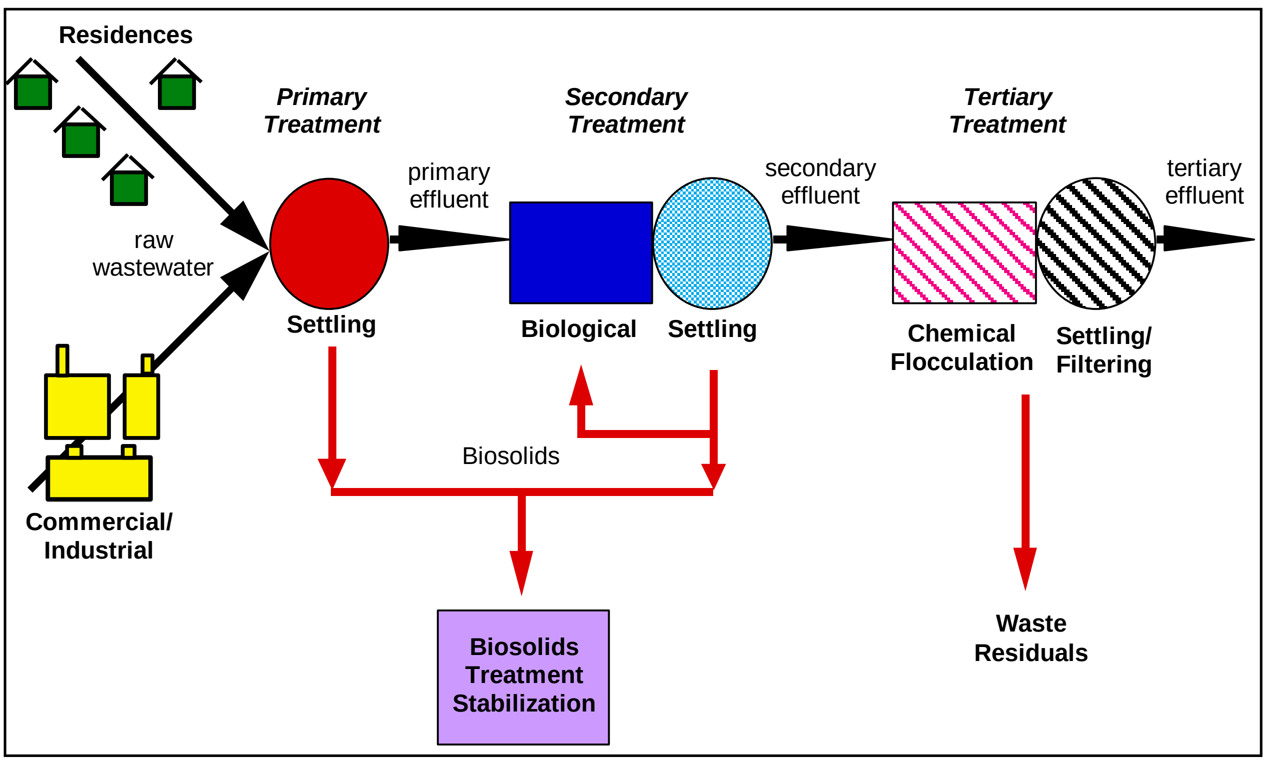


Figure 1. Schematic representation of wastewater collection and treatment.

High Nitrogen Biosolids

High N biosolids (total nitrogen content ranging from 3-6%) are generally more reactive due to a shorter stabilization period. They are excellent fertilizer sources and generally require a few months to stabilize when applied at high rates. They contain a high fraction of short chain organic compounds that are easily decomposed, thus they encourage high rates of biological activity after application. These materials often contain organic polymers that have been added to aid in dewatering. Examples of high N biosolids include anaerobically-digested, lime-stabilized, and heat-treated materials. These descriptions refer to the various treatment processes that are used to stabilize biosolids and reduce pathogens to meet Class B application requirements (EPA 40 CFR Part 503, http://www.epa.gov). Lime addition reduces pathogens, causes a portion of the nitrogen to volatilize, and also results in a higher solids content. While lime stabilized materials may have N concentrations and solids content typical of low N materials, they are still highly reactive and should be grouped with the high N materials.

Low Nitrogen Biosolids

Low N biosolids are generally more stable than high N biosolids, with total nitrogen ranging from 1-3%. These materials are generally treated in lagoons or drying beds where the average residence time may be several years. Polymers, when used, decompose during this period. Low N biosolids are less reactive and less readily decomposed than high N biosolids. They also tend to have a higher solids content. Low N biosolids are also excellent fertilizers; however, generally higher application rates are usually required to meet the N needs of a crop.

Biosolids Composts

Both high and low N biosolids may be used as part of the feedstock for producing composts. Composting often comprises a portion of a municipality's biosolids program. Composting

biosolids require a long residence time (1-4 months). These materials are generally produced for the home gardener or landscaper, therefore the final product must be highly stable and screened to a small particle size. As a result, composts tend to be the most expensive of all types of biosolids products. Therefore, the use of compost in restoration may not be the most cost effective option. One way to lower the costs associated with compost use is to use compost that has not been screened or completely cured, as both long detention times and screening add significant costs to the process. These less stable materials are much cheaper to produce and can be obtained by working with a municipality or composting operation to specify the type of product required.

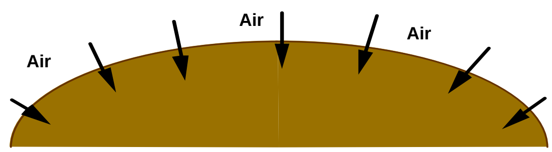
Composts tend to have low fertilizer value and are used primarily as a soil conditioner. However, they can also be used to create a new soil horizon. High rates of compost are required for restoration (a 3" application is usually sufficient to create a new soil horizon on disturbed, non-toxic materials). They are appropriate for use in high population areas and in areas bordering roads and streams where potential erosion of less stable materials is a concern. They can also be used as a border material in projects that primarily use biosolids. Composts are also highly effective for use in wetland restoration and construction. They are stable, high carbon (C) materials that are similar to the organic material found in naturally occurring wetlands.

Low-tech Compost Production Methods

There are at least three relatively low-tech ways to produce compost from biosolids:

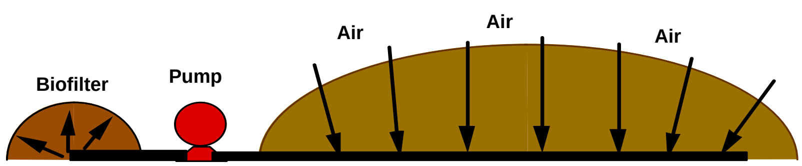
Static Pile Composting

Biosolids (mixed with a low surface area carbonaceous material, such as hog fuel, as a bulking agent) can be set in piles and left to cure for 4 or more months. Little odor will be created except during pile building, and extraction of composted material for land application.



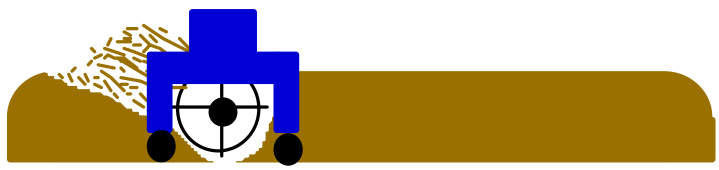
Aerated Static Pile

This method is similar to the one described above, with the notable exception that air is either forced into or vacuumed out of compost piles. This greatly reduces the composting time. For restoration use, composting time is reduced to just 1-2 months. Little odor is created except at pile building. Continuous aeration should keep the pile mostly aerobic and greatly reduce odor production. Some odor generation can result if the pile is force aerated. If air is pulled through the piles, however, it can easily be treated by a biofilter. No odor should be produced when the compost is finally extracted for application.



Windrow Composting

Biosolids and bulking agents can be set out in windrows. The windrows are turned by a specialized turner, or a loader as temperature dictates (generally 1-3 times per week) to ensure adequate aeration. This type of composting also produces a product for suitable for restoration use within 1-2 months. Odor will be produced at each turn of the compost pile. Similar odors will be produced when the compost is finally extracted for application.



Materials for Composting

If biosolids are used as the primary ingredient to be composted, a bulking agent must be added to aid in aeration. A number of materials are suitable for this purpose, but a carbon-rich material is commonly used. Materials are often added simply to "dry out" the biosolids to about 40% solids. This can be accomplished with woodchips at a volume ratio of about 3:1 woodchips to biosolids, or a dry weight ratio of about 7.5:1 woodchips to biosolids. If a yard waste with higher moisture than woodchips is used, a greater ratio is required. Raw materials that go into the compost piles will lose both volume and weight through the decomposition process. With the use of biosolids and a woody bulking agent, a volume loss between 25-50% can be expected.

USES FOR BIOSOLIDS

Determining the Problems

Biosolids can be used to remedy a number of problems that may potentially contribute to a soil's inability to support a vegetative cover. It is important to first understand what factors are preventing plants from growing at a particular site. There are several soil tests that can be used to determine the nature of the problems. A history of a site can also be useful when attempting to understand what is preventing plants from growing.

The primary variables to test are soil pH, soil fertility, soil physical properties, and potentially toxic concentrations of trace metals. All states have land grant colleges; these generally have soil testing labs that are able to perform these analyses. Land grant universities have agricultural schools and are usually known as "X" State University. While the purpose of these labs is to do research, generally they are asked to test agricultural soils rather than disturbed soils. It is very important to be clear that the sample submitted for analysis is from a disturbed site. Specifying the tests which are to be run is also important. Soil testing labs at land grant universities generally use extractions designed for the soils that are common in their particular state to determine fertility. Soils at disturbed sites may have very different properties that make these extractions less valuable. County extension agents can also help locate soil testing labs.

pH

Appropriate soil pH for plant growth is generally between 5.5 and 7.5. A hand-held pH meter can be used to measure soil pH. Mix soil and water at a 1:1 or 1:2 volume ratio and let it sit for an hour. The slurry will then be ready for pH measurement. All soil testing labs are equipped to do this measurement. If the soil has high levels of trace metals (e.g., Zn, Pb, Cd) part of the remediation goal will be to increase soil pH to ≥7.0. Metals are much less soluble at high pH levels, making them less bioavailable. An appropriate way to determine a good pH goal (assuming that metals are not an issue) is to look at the pH of soils in the area. The soil test lab can usually provide this information and suggest an appropriate amount of lime to add based on the soil type and soil pH.

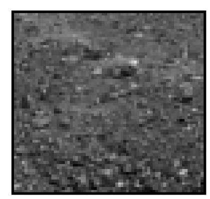
An important factor to consider, when looking at soil pH, is the potential for the soil's acidity to increase over time. For example, certain mine tailings have very high sulfur (S) content. Initially the S is in a reduced form, however, as the S is exposed to air and moisture, it will oxidize and generate sulfuric acid. When working with high S residuals, potential and actual acidity need to be taken into consideration. There are special tests that can be run to determine potential acidity. Dennis Neuman (dneuman@montana.edu) and Douglas Dollhopf (dollhopf@montana.edu) at Montana State University and Lee Daniels (wdaniels@vt.edu) at Virginia Polytechnic, specialize in remediating soils with high acid generating potential and can test soil for a lime requirement that takes this potential into account.

Soil Fertility

Soil fertility is the most common test performed by any soil test lab. Three macronutrients that are generally tested for are nitrogen (N), phosphorus (P), and potassium (K). Soil test results for these nutrients are generally reliable. Nitrate (NO_3^-) and ammonium (NH_4^+) are the principle forms of nitrogen that are "plant-available" and total nitrogen in a soil test will not reflect this. Phosphorus is the only macronutrient whose test results may not be appropriate. Phosphorus is relatively stable in soils; it will generally precipitate and only a small fraction of total soil P is plant available at any time. In the case of mine tailings or metal contaminated soils, P is very often deficient. Adding sufficient P to provide excess for plant growth is important at these sites as plants can inadvertently access trace metals in their efforts to increase the P supply. In cases where zinc (Zn) or lead (Pb) is present, excess P should be added to the soil as part of remediation.

Soil Physical Properties

In many cases, disturbed soils have a very poor water holding capacity. This can make plants grown on the sites very susceptible to drought. Organic matter addition can greatly increase a soil's water holding capacity. Adding organic matter can also increase percolation and enhance soil aggregation (cementing of particles into small clumps instead of being dispersed).



Soils generally contain from 1-8% organic matter with higher values found in areas with colder climates, fine soil texture and high rainfall. In attempting to reclaim a sand pit in New Mexico, the goal for total organic matter will be much less than if working with a soil in Wisconsin. Soil labs can test soil for total carbon using a CHN (carbon hydrogen nitrogen) analyzer. The results from this analysis can help to determine how deficient the soil is in organic matter. Generally, extra organic matter can only benefit a soil. When working with mine tailings or overburden, organic matter always improves soil properties.

Trace Metal Concentrations

Although high levels of certain metals can kill plants, many of these metals are also necessary micronutrients for plant growth. Soil labs routinely test for micronutrients like zinc (Zn), manganese (Mn), copper (Cu), and iron (Fe) using extraction procedures to assess potentially deficient conditions. These test methods are not appropriate for potentially toxic conditions or detection of nutrient imbalances. The best tests to use for these situations are procedures that measure total metals, such as a wet digestion. Total concentrations can indicate whether the soil is in a potentially toxic range for certain elements, as well as indicate potential deficiencies in others. Plant availability of these metals is highly pH dependent. As the soil becomes more acidic, metal availability to plants increases. A non-toxic concentration of metals at pH 7.5 can be toxic at pH 5.0. pH must always be considered when determining whether metals concentrations are excessive. A range of metal concentrations for normal soils is as follows:

Zn 10-300 (necessary nutrient)	Cu 2-100 (necessary nutrient)
Pb <1-120	Fe 10,000-100,000 (necessary nutrient)
Cd <0.01-2	Mn 20-4,000 (necessary nutrient)

Metal Toxicity

Metal toxicity can occur when a metal, often a necessary plant nutrient, is present in high concentrations. Toxicity becomes more severe at acidic soil pH or when coupled with other nutrient deficiencies. Certain metals are more toxic to plants than they are to humans. An example of this is Zn, which will kill plants in concentrations too low to cause any negative human health effects. Other metals, such as Pb, are generally not toxic to plants but can cause negative human health effects when soil is ingested directly. Plant tissue analysis can help to determine if metal toxicities exit. Commercial labs and land grant universities can generally do plant tissue analysis (grab samples from young leaves of several plants in a field can be combined for analysis). Plant samples should be washed in soapy water, rinsed, and air-dried before being sent to a lab. While toxic concentrations of metals vary across plant species, Zn > 400, Mn > 1000, and Cu > 40 are generally considered to be potentially toxic.

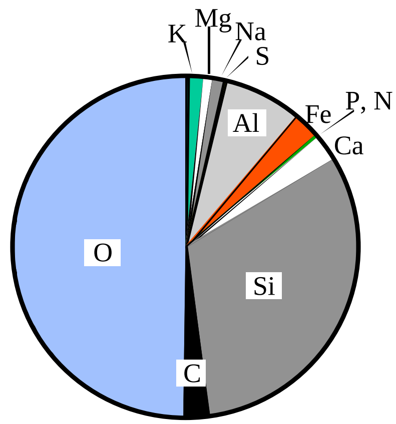
Combination of Factors

In many cases, disturbed sites are barren for a combination of reasons. An example is the case of soils contaminated by smelter emissions. Aerial deposition of contaminants makes the soil surface toxic to new seedlings. As a result, only preexisting vegetation survives. The established growth is weakened by contaminants on leaves. Often, older growth gradually dies out or is killed by fire. Without plant roots to hold soil in place, erosion increases. To remediate this type of soil, a number of obstacles need to be overcome. They include: poor physical properties due to erosion of the surface soil horizon, nutrient imbalances and deficiencies (again, due to the loss of a surface horizon), and acidic, potentially metal-toxic surface soils due to smelter deposition.

In all cases, it is important to understand the range of factors that are contributing to a barren soil. While conventional approaches can be very effective at remedying a particular problem, they are often insufficient for a combination of problems. Biosolids, alone or in combination with other products or residuals, are generally able to remedy a range of problems.

WHY USE BIOSOLIDS?

While other materials, like manure, may also be effective, there are several reasons to use biosolids in reclamation. From a regulatory viewpoint, there are EPA rules (40 CFR 503) that govern the use of biosolids. On a scientific basis, there is an extensive body of research on the use of biosolids, including the use of biosolids for reclamation. From an economic viewpoint, the use of biosolids can be cost effective. All biosolids generators have an associated cost for management, so use of biosolids for remediation can be partially subsidized by the generator. Also, since they have been practicing biosolids application for many years, generators and contractors have an enormous amount of application expertise and equipment required for biosolids application.

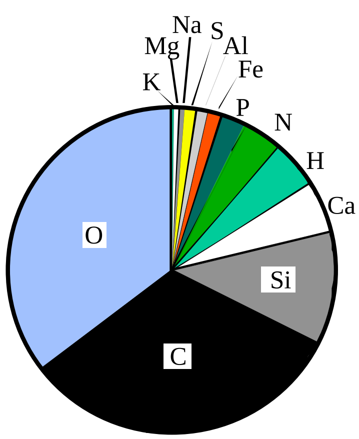


soil

How Biosolids Work

Fertility

Biosolids are generally applied in agricultural soils to meet the nitrogen needs of a crop. By applying material to meet the nitrogen needs, sufficient phosphorus is also applied. Sufficient potassium is generally not provided for in an agricultural application of biosolids and commercial potassium may need to be added. If the only problem at a site is lack of nitrogen or phosphorus, application of biosolids at agronomic rates will more than correct the deficiency. Most biosolids are applied to agricultural or forest soils for this purpose and appropriate rates are generally based on providing 150-200 lbs. of plant available nitrogen per acre. Calculation of an appropriate application rate is common practice for those experienced with biosolids applications. The organic matter that is supplied along with the nitrogen and phosphorus will improve the physical properties of the soil as well, but, as an application at fertility rates is relatively small, improvement of physical properties occurs only over many repeated applications.



biosolids

When attempting to vegetate disturbed mine tailings, unexpected micronutrient deficiencies are not unusual and nutrient imbalances are common. Because biosolids contain all necessary micronutrients in addition to macronutrients, an application of biosolids to meet the nitrogen requirements of a crop will also provide sufficient concentrations of all micronutrients -- and generally in balanced ratios. Rather than attempting to test for a full range of nutrients and develop a customized fertilizer blend, a biosolids application can function as an all purpose fertilizer.

Some special cases exist, such as with lime stabilized biosolids added at high rates to light textured or sandy soils. If the lime added to the biosolids is primarily a calcium rich material, there may be a potential for a long-term magnesium deficiency. This can be avoided by the addition of a high Mg product, such as dolomitic limestone, to the application mixture.

pH

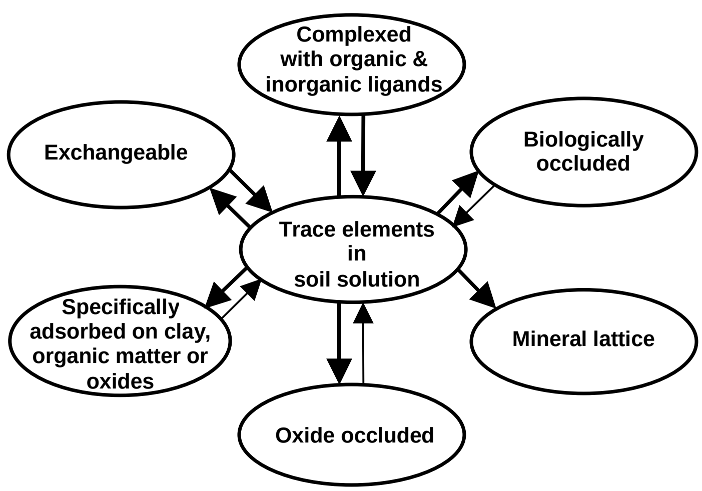
Biosolids can sometimes be applied to correct soil pH. To meet requirements for pathogen and vector attraction reduction that is outlined in 40 CFR 503, some treatment plant operators add lime to biosolids. Lime is generally added at a rate of 20-50% solids in order to reduce pathogens. This product is generally referred to as lime stabilized material. Application of lime-stabilized biosolids can very effectively correct soil pH. Applied at high rates (> 100 dt/ac), these materials have been shown to correct subsoil, as well as surface, acidity. If locally available materials are not lime-stabilized, limestone or a high lime residual such as coal fly ash (produced by burning high sulfur coal), wood ash, cement kiln dust, or sugar beet lime can be mixed with the biosolids. Addition of a high calcium carbonate residual to biosolids will volatilize much of the ammonia in the biosolids, reducing the nitrogen value of the amendment.

Soil Physical Properties

In many cases, poor soil physical properties are responsible for poor plant growth. When attempting to establish a plant cover on a disturbed site, poor water holding capacity and poor water infiltration/percolation can lead to droughty conditions. Addition of organic matter to soil will improve both properties. Organic matter also helps to form stable soil aggregates which increase water infiltration and percolation. As biosolids are generally 50% organic matter, biosolids application will improve the physical properties of a soil.

Trace Metal Toxicity

Much of the initial research on biosolids centered on the potential for trace metals in biosolids to cause negative human health effects. A range of pathways that outline 14 major ways that metal in biosolids could potentially negatively impact human, animal and plant health was developed (http://www.epa.gov/owm/). The metal perceived to pose the greatest potential human health effect was cadmium (Cd). One of the primary ways that Cd can potentially harm people is via consumption of plants grown on high Cd soils. Cadmium can accumulate in plants in concentrations that are potentially high enough to negatively affect people without affecting plant yield.



Early studies were done with Cd salts added to soils to predict what happens when Cd from biosolids was added to soils. What was shown in the studies, however, was that biosolids Cd does not behave like Cd added as salts. Plant uptake in biosolids amended soils was consistently lower than in salt-amended soils. This phenomenon has been attributed to the ability of biosolids to bind trace metals. Biosolids generally contain iron at > 1% as well as manganese at ≥ 0.1%. These elements form highly amorphous minerals that are capable of forming specific bonds with trace metals. Once complexed, the trace metals are not plant available, rendering them non-toxic *in situ*. As metals in biosolids have decreased due to pretreatment regulations, biosolids can now be used to bind trace metals. Biosolids and biosolids compost additions can reduce plant uptake and bioavailability of zinc, lead, and cadmium.

Use of Biosolids with Other Materials

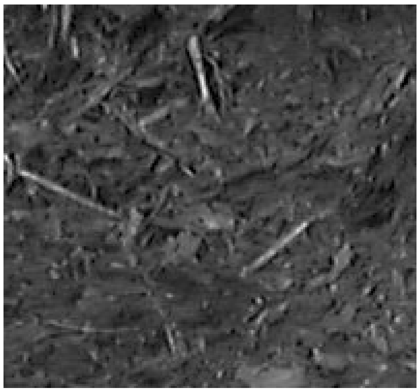
Lime or Residuals with High Calcium Carbonate Equivalent (CCE)

Blending biosolids with other residuals or with other products can result in an excellent soil treatment. The most common type of material to blend with biosolids is limestone or a residual with a high calcium carbonate equivalent (CCE). The materials are easily mixed using a low-tech approach. Once an appropriate dry loading rate of each material is determined, a front end loader can mix materials by adding the proper number of scoops of each to a pile and giving the pile a few turns. Too much mixing can give the amendment a gel-like consistency that makes spreading difficult when using a vehicle with flinging or other throwing mechanisms.

Commercial limestone is available as agricultural lime (primarily $CaCO_3$), or burnt or slaked lime (CaO or CaOH). Another form of agricultural lime is dolomitic limestone. This material has high Mg, as well as Ca, contents. These agricultural limes are generally slow reacting and are about pH 8.3. The other forms of lime are much more reactive and are generally greater than pH 10. Some examples of residuals with high CCEs include wood ash, coal fly ash from plants that burn high sulfur coal, sugar beet lime, cement kiln dust, and ash from burning pulp and paper sludges. The pH of the amendment will vary depending on the form of Ca in the residual. The generator of the material often knows the CCE of the residual. It can also be easily calculated by looking at an elemental analysis of the material. The elemental analysis should list the total Ca (% weight x 2.5), Mg (% weight x 4.2), and K (% weight x 1.3) in the material in order to calculate the CCE of the residual.

With less reactive materials, the amount of ammonia that is volatilized from the biosolids should not be critical to germination. It may be possible to add a seed mixture directly into the amendment immediately prior to application. This approach has been successful at a NPL site in Palmerton, PA where fly ash was mixed with biosolids. In the case of more reactive forms of lime, however, the increase in pH will be sufficient to cause a sizeable fraction of the ammonia to rapidly volatilize, at a rate sufficient to kill any seeds added directly to the amendment. For these types of mixtures, a waiting period of several days is recommended before seeding amended areas.

Residuals with High C:N Ratios



Other amendments commonly added to biosolids may include residuals with high C:N ratios. When biosolids are used for reclamation, rates higher than those used for agronomic applications are generally required. In most cases, excess N is added to the soil. Previous studies on sites where a range of rates of biosolids have been used for reclamation have shown that there is generally a one-time spike in N concentration in surrounding waters following application. If there is concern about excess N entering neighboring streams or into groundwater, addition of a residual with a high C:N ratio may be appropriate. Examples of these types of materials include sawdust, straw, primary pulp and paper sludge, log yard debris, and cotton gin waste. By adding these materials to biosolids, the excess C in the high carbon residual will increase the C:N ratio of the mixture, and immobilize the N. While total C is not always an indication of how easily biodegradable a material may be, a target C:N ratio of 30-40:1 for the mixture is generally appropriate. Amendments with a high nitrogen content, or low C:N ratio, may encourage establishment of exotic species that may have otherwise been held in check by local soil conditions.

Correcting Micronutrient Imbalances

Generally, biosolids applications at restoration rates provide more than adequate levels of all necessary plant nutrients (with the possible exception of K, as noted). However, in special cases, addition of a micronutrient source may also be required. Examples of this include cases of high nickel (Ni) soils, where addition of iron (Fe) to reduce Ni availability may induce a Mn deficiency. Addition of Mn as commercial fertilizer salts can alleviate these deficiencies. Another example is cases of Cd contamination. When Cd alone is present in elevated concentrations, addition of materials with sufficient Zn is required to bring the Zn:Cd ratio to greater than 100:1. Addition of biosolids alone may be sufficient to accomplish this. If not, supplementing the biosolids amendment with a Zn fertilizer may be required.

OBTAINING BIOSOLIDS

All municipalities generate biosolids. As outlined in the Clean Water Act (PL 92-500), all municipalities are responsible for biosolids management; either use or disposal. Municipalities use a range of programs to meet this requirement. Programs can include direct application to agricultural land, composting, use in reclamation, surface disposal, incineration, or landfilling. Approximately 60% of all biosolids generated are beneficially used. Beneficial use is encouraged under EPA 40 CFR 503. Most municipalities subsidize the costs of use or disposal options.

EPA Officials

Each EPA region has a biosolids coordinator. Biosolids coordinators are generally an excellent source of information on the availability of biosolids within a particular region. They can often provide direct contacts to generators and may be willing to assist in making arrangements for the use of materials in reclamation projects. A list of these contacts can be found in Appendix A.

Survey

A national inventory of biosolids is being prepared by Bob Brobst, (brobst.bob@epa.gov), the Region 8 biosolids coordinator. This inventory includes information on biosolids currently being generated in the country. Information on treatment process, quantity, and quality is included. The survey provides information on the current uses of biosolids for each municipality, as well as contact names. This survey can be used for identifying sources of materials.

Municipalities

Municipalities can also be contacted directly in order to procure biosolids. The wastewater treatment department of any city is where to find the people that work with biosolids. Many municipalities operate biosolids use programs without the use of private companies. Some of their primary concerns are: cost, development of long-term use sites, and public acceptance. If a municipality beneficially uses its material, obtaining biosolids for remediation is generally possible. It is important to understand that large municipalities -- those that will primarily be involved in restoration projects requiring large quantities of biosolids -- generate material on a daily basis. Most cities are not able to stockpile biosolids. So, from a generator's perspective, it is extremely important to preserve current users of materials, as they need to be assured long-term use sites for biosolids. This should be considered when negotiating with a municipality. For instance, if, by working with a municipality, an arrangement can be made to get sufficient biosolids over time, rather than requiring them to abandon completely their existing buyers/users, a mutually beneficial agreement can be reached. This will require either stockpiling materials on site or prolonging the time period of reclamation activities while materials are being delivered. In the majority of cases, the municipality will arrange for transportation of materials as part of their normal operations. Similarly, they can often arrange for application and incorporation of biosolids.

It is also important to understand that certain municipalities in areas of high population densities have difficulty identifying local use sites for their materials. These cities (for example New York and Boston) often use rail lines to transport biosolids as far as Texas and Colorado for agricultural use. If the project is far from a large municipality, but close to a rail line, materials from high population areas may be a cost-effective option.

If a municipality currently disposes of, rather than uses, its biosolids, acquiring material for beneficial use may require a number of extra steps. All biosolids that are used for land application are required to meet Class B criteria for pathogen reduction. If a municipality landfills its biosolids, the biosolids may require additional processing and stabilization to be suitable for land application. While treatment facilities can often be retrofitted for additional processing, the additional associated expense and limited need (apart from restoration projects) for Class B materials may discourage treatment plant operators from doing so.

There are a number of organizations to which municipalities belong to that can be sources of information for obtaining biosolids. The best are those like the Northwest Biosolids Management Association (http://www.nwbiosolids.org), the New England Biosolids & Residuals Association (http://www.nebiosolids.org) or the Mid-Atlantic Biosolids Association (http://mabiosolids.org) that can not only identify sources, but can help put projects together on a cooperative basis, and even arrange multiple sources of residuals for a project. There are a number of these organizations currently being formed throughout the US such as the Southern California SCAP by Ray Kearney (rjk@san.ci.la.ca.us).

Other organizations can also provide leads for biosolids sources. The Water Environment Federation (http://www.wef.org) is an organization of practitioners, wastewater plant operators and private contractors in the industry. Regional groups of WEF may be contacted to identify sources of materials within a particular area. Additionally, large municipalities belong to an organization called Association of Metropolitan Sewage Agencies (http://www.amsa-cleanwater.org), which can suggest possibilities. Currently, there is a National Biosolids Partnership (http://biosolids.policy.net) among EPA, WEF and AMSA to help promote environmentally sound biosolids management, so help from each or all of these organizations is highly likely.

Private Companies

Private companies also handle biosolids and will contract with a municipality for use of their biosolids. The companies are paid a fee by the municipality to apply and can arrange for materials delivery and application. These companies are easily contacted through advertisements in wastewater, biosolids and organic residuals journals (i.e., the WEF journal, or BioCycle).

How Much do Biosolids Cost?

Under the Clean Water Act, all municipalities that generate biosolids are responsible for their management -- use or disposal. Beneficial use for agriculture, silviculture, and restoration are recommended end-uses for biosolids under this act. Generally, a municipality will have developed a range of beneficial use options or will have paid a contractor to develop a beneficial use program. In all cases, the municipality has costs associated with biosolids use or disposal. It is also the goal of all municipalities to reduce these costs. When approaching a municipality, it is important to fully appreciate both of these factors. In certain cases, the municipality or contractor will willingly provide and incorporate biosolids at no charge. In many cases, a token payment will be required. Some municipalities may look at restoration projects, particularly those under the Superfund umbrella, as having very deep pockets. They may attempt to have the restoration project cover all transportation costs and even request payment for materials. In these cases, negotiations are necessary. It is important to have an understanding of the normal costs covered by municipalities when negotiating agreements.

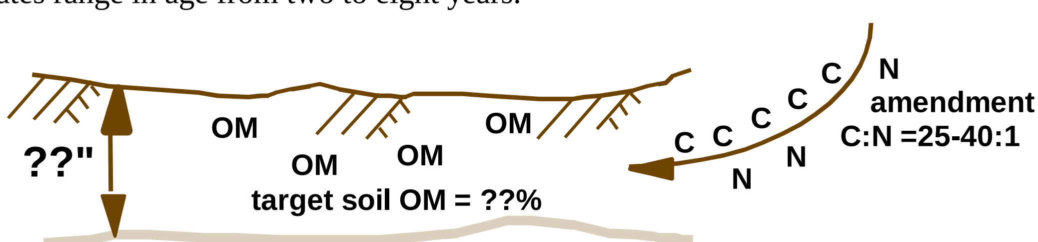
The beneficial use costs of a city with an award winning use program can be used as an example. Costs for biosolids use in this city have decreased by over 33% in the last ten years due to increasing options and corresponding demand. Currently the city uses a three pronged approach for biosolids use. A portion of the biosolids is sent to a private company to be composted. Transportation costs, as well as composting costs, are covered by the municipality, bringing the cost of this process to > $35 a wet ton. An additional portion of biosolids is used for forest application. The municipality pays about $12 a wet ton for transport and an additional $5 per ton for application. The bulk of the biosolids are used as a fertilizer in agricultural soils with transportation costing approximately $30 per wet ton and incorporation costing $2-3 per ton. The farmers pay the municipality $1-2 dollars per ton in exchange for the biosolids.

It is important to work with a municipality to develop an appropriate time line for materials delivery and incorporation, as well as determining the amount of biosolids that can be provided within a particular timeframe. Working together and showing some flexibility can make the cost of biosolids application a reasonable fraction of total project costs. In addition, using the expertise and equipment of the biosolids generators for application can greatly reduce the cost of operations.

DESIGN AND PERMITTING PROCESS

Determining Appropriate Biosolids Rates

Determining an appropriate application rate, unfortunately, is not a matter of rigorous science. Older restoration projects using biosolids generally used rates in excess of 100 dry tons/acre. There was generally the perception that more biosolids would result in longer-lasting and more effective restoration efforts. While addition of high rates of materials will often have a positive effect, cost concerns may outweigh this. There has been some research to determine appropriate rates at the lower end of the scale. With only a shallow horizon of contaminated soil, application rates of 25 dry t/ac were found to be equivalent to 50 and 75 t/ac in Palmerton, PA, where an application of 25 dry t/ac in combination with fly ash has maintained a stable vegetative cover for eight years. A project in Silesia, Poland found that 100 t/ac was necessary to establish a vegetative cover on slag piles, while work in Bunker Hill, ID indicated that a higher application rate of a drier biosolids was required to achieve even coverage. As use of biosolids to restore metal contaminated sites is a relatively new practice, it is not yet possible to say whether lower rates are as effective as higher rates over the long term. Areas that have received higher rates are showing a self-sustaining cover up to 30 years after biosolids application. Projects using the lower rates range in age from two to eight years.



Factors to be considered in determining an appropriate application rate are depth and levels of contamination. The deeper and more contaminated sites suggest that higher application rates be used. For example, in cases where a plant cover is to be established on mine tailings with Zn concentrations in excess of 10,000 mg/kg and an acidic soil pH, a higher application rate of 100 t/ac or greater would be appropriate. Where tailings are calcareous and have lower metal concentrations, 25-50 t/ac should be sufficient. Brown field sites with highly variable concentrations of contaminants may also be restored successfully with lower rates.

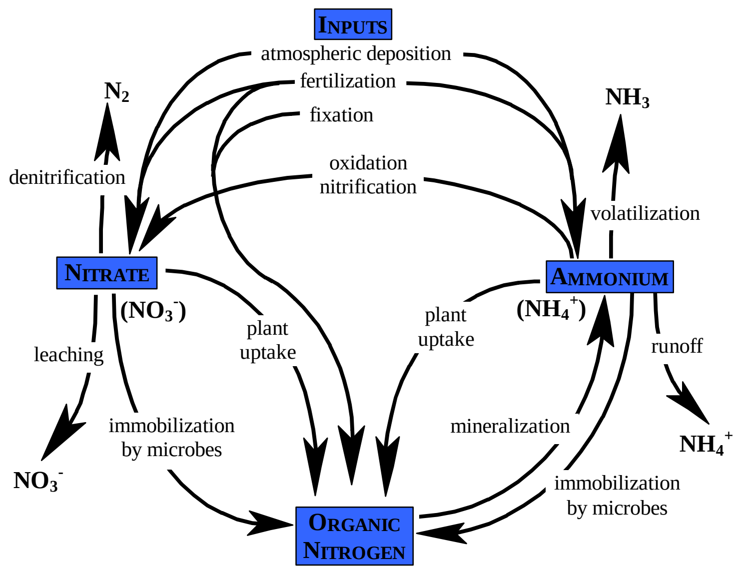
Rates Determined by Depth of Application

To create a "soil horizon" by biosolids or biosolids products, approximately 115 dt/ac of stable material for every inch of soil built up is required. However, over the first year or so, up to 25% of the fresh biosolids mass may be lost to decomposition, depending upon the biosolids stability at time of application. Thus, the applied amount required may be about 150 dt/ac. Since biosolids generally range from 15-30% solids, every inch of soil requires a wet depth of biosolids over 6 inches (assuming 20% solids).

Similarly, one must consider the reduction of volume of compost material in the years following application as the organics decompose (depending upon the characteristics of the compost, greater than 25% of the volume). Thus, a desired depth of compost of 1" should receive an application of 1.3", or about 180 cy per acre. In terms of dry weight loading, this is about 50 dt/ac (at a bulk density of about 20 lbs/cf) per desired final inch of soil compost.

Nitrogen Management

One major consideration of heavy applications of biosolids is nitrogen management. An application of 100 dt/ac may contribute up to 10,000 lbs-N/ac (at 5% N); half of which may be in an available form during the first year. This amount of available N (initially in an ammonium form) will either volatilize or be transformed into nitrate. Two associated concerns exist: nitrification is an acidifying process; and high potential for high rates of nitrate leaching. This needs to be considered in terms of groundwater impacts. If biosolids for the project are lime stabilized, the total N concentration will be lowered by dilution, and the lime added to the biosolids during treatment will maintain soil pH and also increase N volatilization.



An alternative to high biosolids only applications, which both reduces the N loading and may actually conserve excess N from the biosolids through immobilization, is co-use of a carbon-rich residual. In this case, biosolids can be applied to the soil in combination with sawdust, primary pulp and paper sludge, paper waste or even some types of yard waste (those that include a significant amount of woody debris). This limits the potential for excess N to nitrify and leach from the site. Adding biosolids in combination with a high C material directly to the soil essentially allows it to compost in place. Total cost for this option would be transportation of materials to the site and direct application of the materials. In normal practice, either: (a) alternate layers of biosolids and C-rich material are laid down, then incorporated; or (b) materials are mixed on site prior to application. Because a C-rich residual is often considerably drier than biosolids, it is much easier to work the soil after application.

pH Adjustment

Determining the appropriate application rate for lime is very important in cases of metal contamination. Plants generally require a pH > 5.5 for good growth. In cases of metal contamination, pH > 7.0 will limit the solubility of metals by both increasing the number and strength of binding sites and decreasing the potential for soluble stable species. It is important to add sufficient limestone to raise soil pH in the surface 18” of soil and to keep it well buffered.

Procedure

Soil samples can be collected in 6” increments. pH measurements should be made on the dried and sieved subsamples. There are standard EPA procedures to determine the lime requirement of a soil. An alternative test is as follows: base (such as 1 M KOH) should be added to 10 g subsamples of the soils that have been mixed with 20 ml of water. A good starting point is addition of 1 ml of 0.8 M KOH, which is equivalent to the addition of 8 t/ac of limestone for the 6” portion of the soil profile. The pH of the soil/water slurry should be taken 1 hour after water addition. The base should then be added and the sample put on a side to side shaker for 24 hrs. The pH of the sample after shaking will be comparable to the pH of the field soil after limestone application. If this is sufficient to bring the pH > 8.5, the amount of lime added is sufficient to neutralize that portion of the soil. If the base brings the pH of the sample to >10.5, then the CCE added is more than required. Redo the incubation using a lower rate of KOH addition. Add the adjusted lime requirements for all horizons tested and you will have your lime requirement for the profile. This is a relatively quick procedure to determine the lime requirement for a site where acidity is an obstacle to revegetation. It is appropriate to use this type of procedure, rather than simply consulting the soil test lab or an agricultural extension agent when you are working with heavily disturbed soils or mine tailings.

High Sulfur Sites

In cases where soils are contaminated with high S minerals or where high S is present, it is also necessary to account for the acidity that can be generated when the S oxidizes when determining the appropriate rate of limestone addition. Sulfur is often present in mine tailings when high S ores have been processed. These ores are stable under anaerobic conditions. As the rocks are ground to small particles and exposed to O_2, the minerals are no longer stable and the reduced S will oxidize. When S oxidizes, it generates sulfuric acid which has an adverse effect on plant growth.

There are a number of procedures to test for the acid generating potential of these types of soils. The best way to test a soil for this type of acidity is to consult with scientists who work with these types of materials. Douglas Dollhopf (dollhopf@montana.edu) at Montana State University and Lee Daniels (wdaniels@vt.edu) at Virginia Tech can test your soil for a lime requirement that takes into account acid generating potential.

Regulations and Guidelines

<u>40 CFR 503</u>

Contaminants – metals and organics
The national regulations that define appropriate use of biosolids are detailed in 40 CFR part 503 (http://www.epa.gov/owm). These guidelines define the maximum metal concentrations that biosolids may have and still be suitable for land application. The basis for 40 CFR 503 is primarily the agronomic use of biosolids. The exposure risk assessment used a pathway approach to evaluate any potential negative impacts as a result of biosolids use and considered soil reclamation in its analysis as well. It also defines the maximum metal concentrations that biosolids may have to be considered exceptional quality materials. These materials may be used without restriction. Currently the vast majority of biosolids produced in the country have metal concentrations well below the requirements. Organic contaminants are not regulated under 40 CFR 503 as concentrations of these materials were well below concentrations that were deemed to pose a potential risk. Radionucleide concentrations were not regulated in the 503's. EPA is currently surveying the radionucleide concentration in biosolids and may issue an advisory or site specific guidelines for these materials. The technical basis for the 503 regulations is outlined in one of the support documents found on the EPA website.

Pathogens
Part 503 also regulates pathogen reduction requirements that are necessary to achieve Class A and Class B standards. Class B biosolids have undergone a Process to Significantly Reduce Pathogens (PSRP). Use of Class B materials has some restrictions. For example: no vegetable crops may be grown on the soil for 18 months following application; material may not be applied within 10 m of streams or rivers; public entry in applied areas is restricted immediately following application. Full details of these restrictions are outlined in the regulations. Most generators and contractors are familiar with these restrictions and can make sure that application is in compliance with the regulations. Most biosolids from larger municipalities that have anaerobic digestion and high N biosolids generally fall under Class B standards. Class A materials have undergone a Process to Further Reduce Pathogens (PFRP), such as high temperature digestion, composting or heat drying. These materials may be used without any restrictions, so long as they also meet the 40 CFR 503 limits.

State Regulations

The 40 CFR Part 503 regulations are the minimum standards for biosolids application. Each state has the freedom to apply more stringent standards than those outlined in 503. The EPA regional biosolids coordinator will be familiar with any additional regulations. Many additional regulations relate primarily to agricultural use of biosolids. Use of material for restoration purposes (generally a one-time application) may be exempt from these additional regulations.

Permitting Process

Permits are generally required for all biosolids applications. This is a good means to gain public acceptance of a proposed remedy even though obtaining required permits can be a time consuming process. Use of biosolids for reclamation is also a recommended use in the regulations. A provision is made within the regulations for application in excess of agricultural rates for restoration objectives: 503.14(d) “Bulk sewage sludge shall be applied…. at agronomic rates…unless, in the case of a reclamation site, otherwise specified by the permitting authority.” Permits may be required on several levels, depending on the particular region of the country. Generally, the permitting process is best left to the experts. If biosolids are obtained through a municipality, generators can often walk the necessary permits through. Another way to obtain appropriate permits is by working with the regional biosolids coordinator.

Public Acceptance

The public has generally accepted the use of biosolids on agricultural lands. This has not always been the case and in some local areas there are still citizens who need to have the benefits of biosolids use demonstrated before public acceptance is achieved. Years of practice in dealing with public acceptance issues have made many biosolids generators public-acceptance professionals. Generally, a successful biosolids project requires a pro-active approach. It is necessary to be very open with local citizens groups about the nature of the restoration project. This includes being straightforward about the materials to be used as well as their origins. Low-keyed informational meetings (as opposed to formal public meetings or hearings) and articles in local papers are very effective means for gaining public acceptance. A large body of educational materials exists that is excellent for use in public meetings. These include videos and pamphlets that describe what biosolids are, the regulations governing their use, and the benefits associated with biosolids use. The generator or contractor providing biosolids for a project may have access to these types of materials. The Northwest Biosolids Management Association (NBMA - contact Leah Taylor 206 684-1145 www.nwbiosolids.org) is an excellent source of general educational material and can also provide detailed literature reviews on the environmental effects of biosolids use.

One of the most often heard objections of those near a biosolids use site is to its unique aroma. Odor can be a challenging obstacle to public acceptance. There are two stages of odor from biosolids. The strongest smell happens immediately after application and is caused by volatilization of ammonia and anaerobic decomposition of sulfur compounds. This dissipates after a day or two. Evolution of different sulfur compounds will result in some less intense lingering odor that will depend upon climatic conditions. Dry and hot or cold conditions will reduce odor intensity in a relatively short period of time, while moist, warm conditions prolong odors. Incorporation also reduces odors. Generally in an agricultural community, familiarity with the use of manure will make acceptance of any odors less of a problem. Use of materials in isolated areas eliminates this as an issue.

METHODS OF APPLYING BIOSOLIDS

Application of biosolids usually requires special equipment to match the characteristics of the biosolids to the individual site. The amount of moisture in biosolids, commonly reported as % solids (a weight measurement of the amount of solids and water in a biosolids sample), is the predominant characteristic that dictates the type of machinery required, the application procedures, and application timing. The solids content of sludge will vary from a dark liquid at 2-3% solids to a semi-solid moist cake-like material at up to 40% solids. Increasing the solids content of biosolids at the Waste Water Treatment Plant is expensive, and a generator whose use sites are within a reasonable distance will generally be satisfied with a more liquid product. Dewatered biosolids, sometimes called cake, have had polymers or lime added prior to belt filter press or centrifuge processing to achieve a 15-30% solids content. They are generally the consistency of gelatinous mud.

Typical ranges of biosolids solids content applied to restoration sites have included liquid sludge at 2-3% or 6-8% which can easily be pumped, semi-solid biosolids at 8-18% solids which can also be pumped (though less efficiently than liquids), and solid biosolids cake at 20-40% solids which may be flung from a manure-type spreader or end-dumped.

Application rates are typically calculated on a dry weight basis. This means that, for an average dewatered biosolids (20% solids), application of 100 dry t/ac would involve applying 500 wet t/ac of material. This is a significant amount of material - almost 5" deep! This quantity suggests simplicity and speed -- a feature of direct spreading! A variety of equipment technologies are available to perform direct spreading, including farm manure wagons, all terrain vehicles with rear tanks and dump trucks.

Heavy applications such as this can be accomplished using two basic techniques, both of which are relatively easy in concept and cost, but require significant waiting periods for the biosolids to dry out.

- Single application. The fastest and most cost-effective method is to make the total application in a single lift. Depending upon application rate and % solids, this may be as little as 1" to up to 30" in depth! Drying of the biosolids at higher depths may require a complete summer period; drying can be enhanced by seeding with a grass that can germinate and withstand the anaerobic conditions of the biosolids. A cereal grass such as annual rye or wheat is generally very effective for this purpose. Once the biosolids have dried, normal farm disks can be used to incorporate biosolids into the subsoils.

- Multiple lifts. Applications of biosolids can also be made in smaller “lifts,” or partial applications. Biosolids are then immediately incorporated into the soil. In fact, in some states, incorporation within a certain time period is a requirement of biosolids management. Incorporation into the soil helps solidify the mixture by dilution of the wet biosolids with the relatively dry soil. However, unless a cover crop is grown before a second application, drying of this mixture may be slower than if the biosolids were simply surface applied. In the case of multiple heavy applications needed within a short period of time, working the soil becomes a definite challenge, as repeated applications followed by mixing without drying will turn the soil into a deep quagmire (potentially far deeper than the actual depth of biosolids added). Because the soil is worked many more times in this method, costs will be significantly higher.

There are several technologies that are effective for applying and even incorporating these rates of materials. Site topography, soil strength, evenness (including debris), and waterways are the physical features that affect equipment selection. Easy access, stable soils and a clear site favor the simple methods, while obstructions or steep slopes require specific equipment. Also important is the application rate, as light applications require a more precise method. The following table summarizes the common types of equipment available to make applications to disturbed soils.

Comparison of different application systems used in remediation sites.

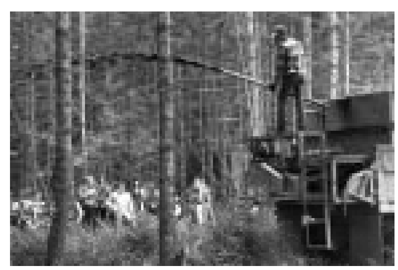
System	**Range**	**% Solids**	**Relative Costs**	**Advantages**	**Disadvantages**
Biosolids dump truck discharge, spreading with dozer	10'	> 12%	Low capital, low O&M	Simple to operate, fast for high application rates	Need cleared, relatively flat site, acceptable to heavy equipment, difficult to get even applications for low application rates
Application vehicle with mounted cannon	125'	< 12%	Moderate capital, high O&M	Can make even applications for low rates, any terrain.	May need special trails with strength for repeated trips, slow.
Application vehicle with rear splash plate	10'	15-35%	Moderate capital, moderate O&M	Can make even applications for low rates, moderate terrain.	May need special trails with strength for repeated trips, slow.
Application vehicle with side discharge	200'	15-50%	Moderate capital, moderate O&M	Can make even applications for low rates, any terrain.	May need special trails with strength for repeated trips, moderate speed.
Manure-type spreader with rear discharge	10'-30'	> 25%	Low capital, low O&M	Can make even applications for low rates, moderate terrain.	Limited to high % solids, trails may need to be close together, moderate speed.

Dump Truck and Dozer

The most basic application technologies use dump trucks and bulldozers. Dump trucks can transport materials directly to the application site and end dump accurately without the need for additional equipment for spreading. Biosolids will "flow" out of a truck and spread to a relatively even depth. The trucks need to dump at appropriate distances from each other to

assure even application. If the soils can not withstand heavy trucks, either dump trucks or other equipment with high flotation tires can be used between the point that the long-haul vehicles can access and the biosolids are used. This equipment may be available from the POTW that supplies the biosolids, potentially for the price of transportation and a small fee. The capacity of the dump truck combined with the loading or application rate can be used to determine how much ground one load of material should cover. A bulldozer can spread the biosolids over that amount of ground. With the right kind of ground (level to gently sloping) and sufficiently dry soils, this can be a quick and cost effective application technology. The bulldozer will have sufficient traction to drive on ground that has already received application. The process should be staged so that the dump trucks (which will not have sufficient traction) dump at the far end of the site first, then move forward.

Application Vehicle with Cannon



An application system suited to liquid biosolids is a vehicle with a tank and spray nozzle mounted on the rear. Depending on the site needs, a specially designed all-terrain vehicle may be used or a simple heavy-duty truck chassis with rear mounted tank may be acceptable. Each of these systems has been demonstrated to be effective in the Pacific Northwest. The operation of these systems is relatively simple. A biosolids source, where biosolids are transferred into the application vehicle, is available either at the treatment plant, through a delivery truck or from onsite storage. Once full, the vehicle moves onto the site and unloads the biosolids in uniform layers while it is moving or stationary. The vehicle then returns to the biosolids source for a refill and the cycle is repeated. The vehicle-tank spray system is patterned after a combination of fire-fighting systems and log skidders (in the case of the all-terrain vehicle). Key features of the vehicular system include: 1) high ground clearance; 2) suspension that increases tire contact with the ground; 3) articulated steering to reduce vehicle turning radius; and 4) low ground pressure, high flotation, high traction and puncture resistant tires. Key parts of the tank-spray system include: 1) as large a tank as possible, mounted low on the chassis for a low center of gravity to reduce roll-over potential; 2) a pressure-vacuum system for biosolids transfer; and 3) a biosolids or solids pump supplying material to a remotely controlled spray nozzle.

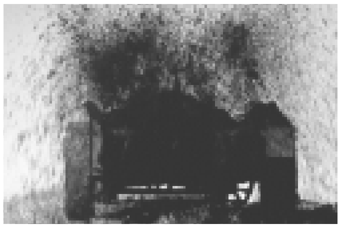
Application Vehicle with Rear Discharge

There are also vehicles that have been specifically designed to apply biosolids to agricultural sites. These typically have flotation tires and a carrying capacity of approximately 18 yards of material. Biosolids are spread from the rear of the box with a fan or splash plate. The width of the spread is comparable to the width of the vehicle. Changing the speed of the vehicle as well as the speed of the fan can alter application rates. These vehicles are excellent for operation on wet soils. The flotation tires generally provide excellent traction and enable access to areas that may not be accessible with conventional equipment. They can spread high or low rates of biosolids or biosolids mixtures onto the surface of a soil. In cases where incorporation is required, additional equipment is needed. Rear discharge application vehicles can also be set up with sub-surface injection equipment which requires a low solids content for proper function. Water can be added to biosolids before application to achieve sufficiently low % solids. The subsurface injection is generally used for agricultural fields that are under a no-till system. It may be appropriate for reclamation projects with relatively low application rates.

Side Cast Spreader

Another type of biosolids application vehicle is a side cast spreader, capable of throw distances of up to 200 ft. Throw distance is dependent on the moisture content of the biosolids, with wetter (15-20% solids) biosolids having a greater throw distance than drier materials such as composts. Application rates can be controlled with this spreader by adjusting the speed of the vehicle as well as the speed of the fan. The spreader can be mounted on a range of vehicles, ranging from a simple truck chassis to an agricultural application vehicle with high floatation tires to all-terrain logging forwarders. The reclamation effort at Palmerton, PA used Aerospreads mounted

on surplus army vehicles. This application method is especially useful on very steep or debris-filled sites.



Manure-type Spreader

Farm equipment that has been designed for manure spreading also works well for many types of soil reclamation projects. A common design is a wagon pulled by a tractor. Typically, these discharge out the back with a large rotary brush.

Incorporation

Incorporation of high rates of biosolids mixtures similarly require the proper equipment and equipment operators. The low % solids of the biosolids means that when making a 100 dry t/ac application, over 500 wet t/ac of material may actually be applied. Generally a large track bulldozer (such as a Caterpiller D7) pulling a 36" disk is required. Smaller equipment will just float on the surface of the biosolids mixture. Large chisel plows also exist that are capable of incorporating the amendments. When incorporating high rates of amendments it will not be possible to achieve a completely homogenous mixture. Although not always necessary, maximizing soil amendment content will increase the effectiveness of the amendment and should be done where practical.

Operator

In most cases, the municipality or private contractor that has applied the biosolids for the municipality will have appropriate application equipment and operators. Arranging for application and incorporation as part of the agreement to use biosolids from a municipality may be the best way to assure appropriate and cost effective application of materials. If the particular municipality does not have appropriate equipment, others will. Examples of municipalities that have large scale application equipment include Chicago (Thomas Granato, 708-222-4063), Virginia (Lee Daniels, wdaniels@vt.edu), Denver (Bob Brobst, brobst.bob@epa.gov) and Philidelphia (Bill Toffee, william.toffey@phila.gov). Bob Bastian (EPA Washington, DC, bastian.robert@epamail.epa.gov) can be contacted as a source of information on application equipment across the country.

SEEDING/PLANTING

Immediate Seeding

There are several options for establishing a vegetative cover on a biosolids amended site. The simplest process involves adding seeds directly to the amendment immediately prior to application. This approach was successfully used at the Palmerton, PA NPL site. Thirty lbs/ac of a grass vetch mixture was hand scattered on the amendment before loading into application vehicles. This is a very efficient and cost effective approach. It is appropriate to use this type of seeding technique with a relatively low cost seed mixture. As only a small portion of the added seed is close enough to the surface after application and incorporation, germination rates of 10-20% are not uncommon. Seeding with an annual rye would be an example of a low cost option that is appropriate for this type of approach.

Delayed Seeding

This approach will not be effective in cases where a highly reactive lime (slaked or burnt lime or a high CCE residual with pH>9) is added to a high N biosolids. These mixtures will release sufficient ammonia to kill any seeds added directly to the mix immediately prior to application. For these situations, seeds can be hand thrown on the surface of the amended soil any time after sufficient ammonia has volatilized (generally a waiting period of three days is sufficient). The surface of a biosolids amended site will be sufficiently irregular that seeds spread on the surface will fall into cracks and crevices and be able to germinate.

It should be noted that use of conventional equipment to spread seed three days after application of high rates of high moisture materials may not be effective. In these cases, the simpler the approach, the more effective and efficient. Hand seeding, using a whirly bird seeder is one approach. Using snowshoes or driving on a vehicle with floatation tires will allow early access to these sites. Biosolids amended soils are sufficiently moist and sticky or adhesive that it is not necessary to hydroseed or to use any tackifiers or mulches. The one exception is when biosolids are being applied in areas where it may be very hot during the growing season. The dark color of the material will increase surface temperature and may kill seedlings. In this case, use of light colored mulch is recommended. On the other hand, the dark color of the biosolids can effectively extend the growing season in cooler areas.

Appropriate Seed Mixtures

In many areas, there is increasing concern with reestablishing native plants on previously disturbed sites. This goal has to be combined with the more immediate goal of establishing a vegetative cover. When high rates of biosolids potentially in combination with other materials have been added to a soil, there are several approaches that may be followed to achieve a healthy stand of native species. Ongoing research to fine-tune these approaches may give different answers over time, but certain approaches seem reasonable.

Initial seeding with high rates (>20 lb/ac) of an annual cereal is generally a very effective approach. Annual cereals such as wheat or rye are inexpensive. There are also varietals that are salt tolerant (high rates of biosolids will increase the electrical conductivity of the soil for a finite period). These materials will germinate quickly and can provide a cover while the amendment stabilizes. Use of lower rates of native species seeds the following season will permit a succession to naturally occurring vegetation. If the area that has been amended is relatively small and is bordered by healthy vegetation, it is also possible to let this vegetation naturally colonize the amended area. If there is no potential for erosion and it is acceptable to leave the amended surface bare for several months, the bordering vegetation will invade the amended areas over time.

A relatively new approach involves cutting mature hay from neighboring fields and using the hay as mulch for the amended areas. The hay should be cut so that viable seeds are included in the hay. These seeds will germinate and the hay will decompose. This is a relatively inexpensive way to establish a native cover.

APPENDIX A: EPA REGIONAL BIOSOLIDS COORDINATORS

Updated November 2001

Names followed by an asterisk have previously been actively involved in use of biosolids for reclamation projects.

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APPENDIX B: SUCCESSFUL PROJECTS

Links or contacts for information on successful projects

- Sally Brown, (206) 616-1299, slb@u.washington
- Chuck Henry, (206) 685-1915, clh@u.washington.edu
- Palmerton, PA, http://www.epa.gov/superfund/sites/cursites/c3pa/s0300624.htm
- Bunker Hill, ID, http://weber.u.washington.edu/~clh/bunker.html
- Coeur d'Alene Wetlands, ID, http://weber.u.washington.edu/~clh/wet.html
- Leadville, CO, http://weber.u.washington.edu/~clh/leadville.html
- Bill Toffee, city of Philidelphia, William.Toffey@phila.gov - coal mine and disturbed soils, NE
- Lee Daniels, Virginia Polytechnic, wdaniels@vt.edu - acidic coal mines, metal toxic soils, Middle Atlanatic, overseas
- Thomas Granato, Chicago wastewater, (708) 222-4063 - coal and disturbed sites